Enantiopure 1,8-Anthrylene Dimer with Acetylene Linkers and an Intraannular Alkyl Group[#]

Shinji Toyota,* Hiroyuki Onishi, Kan Wakamatsu, and Tetsuo Iwanaga
Department of Chemistry, Faculty of Science, Okayama University of Science, 1-1 Ridaicho, Kita-ku, Okayama 700-0005

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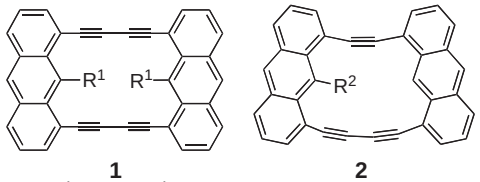
The title cyclic compound with an intraannular ethyl group was synthesized by macrocyclization with the Eglinton coupling and its enantiomers were resolved by chiral HPLC. The high barrier to racemization is discussed in terms of the steric hindrance of the ethyl group with a rigid ring moiety based on the molecular structure optimized by DFT method.

Recently, we proposed a new stereogenic motif consisting of a rigid ring and intraannular chains in our series of studies of anthracene–acetylene oligomers.[1–3] The fact that the motion of intraannular alkyl groups attached to the 1,8-anthrylene–butadiynylene dimer framework in **1** (Figure 1) was markedly restricted by the steric hindrance allowed us to isolate syn and anti isomers at room temperature for both propyl and butyl compounds **1c** and **1d**, which differed in the relative orientation of the alkyl groups. To show versatility of the ring-chain approach, we designed a chiral version of the macrocyclic compounds. In the present study, we used **2**, which consists of two 1,8-anthrylene units with different linkers and an intraannular chain. When the alkyl group is an ethyl group or a longer alkyl group, the tip moiety should point away from the averaged plane of the rigid ring, producing a chiral structure (Scheme 1). Enantiomerization takes place via threading of the tip moiety into the central ring toward the opposite side. To confirm whether such enantiomers are isolable or not, we synthesized compound **2b** bearing an ethyl group at the 9-position of one of the anthracene groups. As this macrocyclic structure was found to be a new ring system, we synthesized parent compound **2a** and compared its properties with those of related dimers having two diacetylene or acetylene linkers.

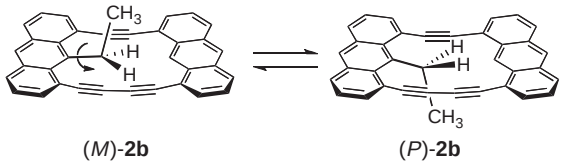
The target structure was constructed from building units **3** and **4** that were prepared by standard methods (Scheme 2).[4,5] These units were connected by the Sonogashira coupling to give acyclic dimers **5**. After the silyl groups in **5** were cleaved off with TBAF, the formed terminal alkynes were subjected to the Eglinton coupling without isolation. The crude products were purified by chromatography to give the desired macrocyclic products in 40% and 47% yields for **2a** and **2b**, respectively. These compounds were obtained as stable yellow solids that had very low solubility in conventional organic solvents.[6] Mass spectra gave molecular ion peaks at the expected molecular weights (*m*/*z* **2a**: 424.1252, **2b**: 452.1532).



1
a: R^1 = H, **b**: R^1 = Et
c: R^1 = Pr, **d**: R^1 = Bu

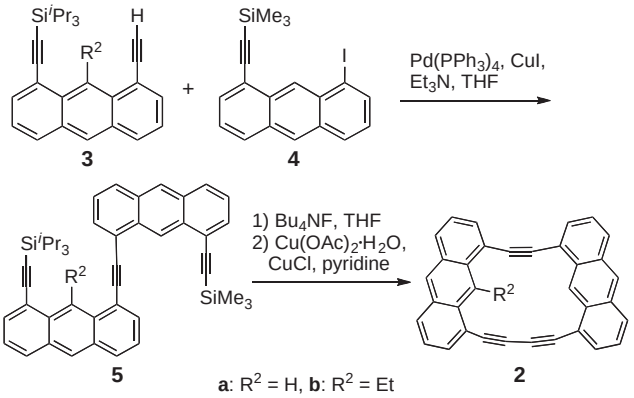
2
a: R^2 = H, **b**: R^2 = Et

Figure 1. 1,8-Anthrylene dimers with acetylene linkers.



(*M*)-**2b** (*P*)-**2b**

Scheme 1. Enantiomerization between enantiomers of **2b**.



Scheme 2. Synthesis of cyclic dimers **2**.

^{1}H NMR signals assignable to the inner protons (9-H) were observed at δ 9.82 and 9.69 for **2a** and **2b**, respectively, and they were shifted downfield compared to the corresponding signals of **1a** (two octyloxy groups at 10-positions) at δ 9.30.[7] Compound **2b** gave complicated signals due to ethyl–methylene protons at δ 4.88 and 5.30 as part of an ABX_3 system, suggesting the presence of a diastereotopic environment in the chiral structure. In the UV–vis spectra, the maximum absorption band at the longest wavelength was observed at ca. 460 nm for **2a** and **2b**. This band was blue-shifted by ca. 30 nm compared with the corresponding band of **1b**.[1,8] Compounds **2a** and **2b** produced emission bands that peaked at 465 and 480 nm, respectively, with moderate intensities.

The molecular structures of **2** were examined by DFT calculation. The optimized structure of **2b** at the B3LYP/6-31G* level is shown in Figure 2. The bond angles at acetylenic carbons are in the range of 170–174°, and this extent of bending deformation is comparable to the calculated structure of **2a** (Figure S1).[9] While the molecule of **2a** is practically planar, the framework of **2b** suffers from deformations due to the steric effect of the ethyl group. The C(9) atom attached to the ethyl group significantly bends away from the anthracene plane. The tip methyl group is approximately perpendicular to the averaged aromatic plane as indicated by the dihedral angle about the C(9)–C(1′) bond. As a result, all atoms belonging to the ethyl group lie on the same side of the averaged plane. These deforma-

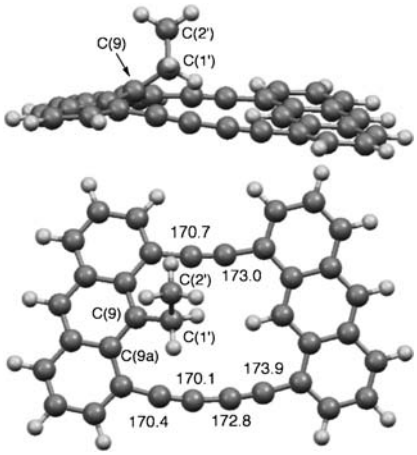


Figure 2. Two views of optimized structure of **2b** at B3LYP/6-31G* level with bond angles at sp carbons. Dihedral angle C(9a)–C(9)–C(1′)–C(2′) −114.4°.

tions relieve the excessive steric congestion in the intraannular region.

The enantiomers of **2b** were resolved by chiral HPLC with a Daicel Chiralpak IA column. The enantiomers were eluted at 31.3 and 33.5 min and showed specific rotations of $[\alpha]_D^{26}$ +163° and −176°, respectively. Their CD spectra are mirror images of each other, and the (+)-isomer features an intense trough at 265 nm and continuous peaks at 270–310 nm (Figure 3). To obtain information on the absolute stereochemistry, the CD spectrum of **2b** was calculated for the M isomer by the TDDFT method[10] at the B3LYP/6-31G* level. The theoretical curve appearing in Figure 3 is consistent with that of (+)-isomer rather than that of (−)-isomer, particularly in the range of 240–300 nm, despite a discrepancy in the long wavelength region due to the systematic shift.[11] Therefore, (+)- and (−)-isomers are assignable to M and P, respectively, designating the helical arrangement of the fiducial groups along the C(9)–C(1′) bond.

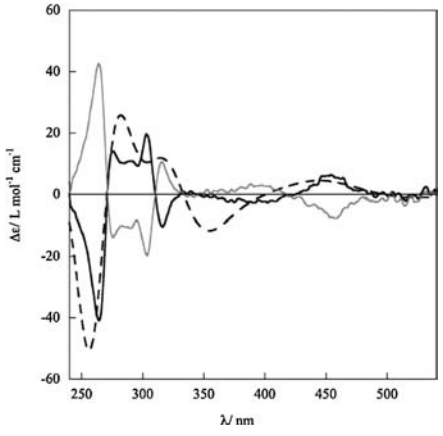


Figure 3. CD spectra of enantiomers of **2b** [black: (+)-isomer, gray: (−)-isomer] and calculated one for M isomer by TDDFT method at B3LYP/6-31G* level (broken line).

No racemization was observed upon heating an enantiopure sample of **2b** at 60 °C for 75 h in hexane, indicating a high barrier to racemization (>125 kJ mol^{-1}). This barrier is much higher than the barrier to isomerization between the syn and anti isomers of **1b** (56 kJ mol^{-1}). This difference means that the short linker or the small central ring dramatically enhances the steric interactions between the chain and ring moieties during the isomerization process as shown in Scheme 1.

In summary, our newly designed π-conjugated system with an intraannular chain allowed us to construct a novel chiral structure, and their enantiomers were successfully isolated. It is notable that even the motion of the ethyl group, the shortest nonlinear chain, is locked inside the rigid framework under conventional conditions. Further studies on the structural modifications of this molecular design, for example, the introduction of larger alkyl groups and the use of smaller ring systems, are under way.

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References and Notes

Part 12 of "Chemistry of Anthracene–Acetylene Oligomers," for part 11, see: Ref. 1.

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